



Assessment of Building Integrated Energy Supply and Energy Saving Schemes on a National Level in Denmark

Münster, Marie; Morthorst, Poul Erik; Birkel, Christoph

Publication date:
2011

Document Version
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):
Münster, M., Morthorst, P. E., & Birkel, C. (2011). *Assessment of Building Integrated Energy Supply and Energy Saving Schemes on a National Level in Denmark*. Danmarks Tekniske Universitet, Risø Nationallaboratoriet for Bæredygtig Energi.

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Assessment of Building Integrated Energy Supply and Energy Saving Schemes on a National Level in Denmark

Marie Münster, Poul Erik Morthorst and Christoph Birkel

Risø DTU

June 2011

Table of Contents	3
Table of Figures	4
Acronyms	5
Foreword	Fejl! Bogmærke er ikke defineret.
1 Introduction	7
2 Scenarios for the Danish Energy system	9
2.1 Scenarios	9
2.2 The base case	10
3 Modelling and data	13
3.1 The STREAM-model	13
3.2 Model implementation	14
3.3 Heat and electricity demand	19
4 Results and Discussion	24
4.1 Changes in energy demand	24
4.2 National energy consumption	26
5 Conclusions and recommendations	32
6 References	33
7 Appendix	34

Table of Figures

Figure 1: Heat and electricity savings in %, achieved by respective scenarios in the district heating and the individual heating sector. Heat pumps are used in the individual sector.	12
Figure 2: Interaction of the individual models in STREAM	13
Figure 3: Hourly electricity and heat demand profiles (maximum savings scenario) of one single family home in the district heating domain for the period of one week.	20
Figure 4: Hourly electricity and heat demand profiles (maximum savings scenario) of one single family home in the individual heating domain with the use of heat pumps for the period of one week.....	20
Figure 5: Change in demand with respect to the single family homes from period of 1961 to 1972	24
Figure 6: Change in demand with respect to the national demand	24
Figure 7: Change in fuel consumption for electricity and district heat production with respect to the national consumption.....	27
Figure 8: Fuel use for space heating in the residential sector, reference scenario.....	27
Figure 9: Fuel use for district heating boilers	28
Figure 10: Fuel mix for electricity generation.....	28
Figure 11: Changes in total gross energy consumption [PJ] divided on fuels used by different technologies.....	29
Figure 12: Change in CO ₂ emissions from energy conversion with respect to the reference on a national scale	31

Acronyms

ct.	(Euro)cent
CHP	Combined Heat and Power
CO ₂	Carbon dioxide
EU	European Union
GWh	Gigawatt-hour
i.e.	<i>id est</i> (that is)
kW	Kilowatt
kWh	Kilowatt-hour
MW	Megawatt
MWh	Megawatt-hour
R&D	Research and development
RES	Renewable energy sources
toe	Tonne of oil equivalent
TJ	Terajoule
TWh	Terawatt-hour

Preface

Until now buildings are most seen as creating a demand for energy. However, if we want to develop an energy system being independent of fossil fuels in the future, this will require new higher standards for energy efficiency and a radical introduction of new and renewable energy technologies, all together implying that buildings in the future might act as prosumers that is both demanding and producing energy.

In this report we look at the overall consequences for the energy system of introducing new technologies as photovoltaics and heat pumps in combination with strong energy conservation measures. A number of energy system scenarios are prepared based on technical simulations for single-family houses carried out by the University of Aalborg.

Project objectives:

This report is part of the Energy research project “Building integrated energy supply” (In Danish: Bygningsintegreret energiforsyning). The main objectives of the project are to:

- Describe different possible technological solutions as integrated parts of the buildings energy supply
- Evaluate these solutions with regard to efficiency, environmental impacts and economy
- Perform energy system analyses of combinations of the above-mentioned technologies including the economic and environmental consequences.

Project Partners:

- Aalborg University
- The Danish Technological Institute
- Risø National Laboratory for Sustainable Energy, Technical University of Denmark

Acknowledgement

The Building Integrated energy supply Project is supported by the Danish Energy Research Programme (Energiforskningsprogrammet EFP) for which we are grateful. The sole responsibility for the content of this document lies with the authors. It does not represent the opinions of the funding organization.

Contact person:

Poul Erik Morthorst
Risø National Laboratory for Sustainable Energy, Technical University of Denmark
Systems Analysis Division
P.O. Box 49
DK-4000 Roskilde
Denmark
Tel. (+45) 4677 5106
E-mail: pemo@risoe.dtu.dk

1 Introduction

In general the European Community is facing two major challenges within the energy field:

- 1) *The combat of climate change.* Current energy and transport policies imply that EU CO₂ emissions are to rise by approx. 5% by 2030. Global emissions are expected to increase by 55% in the same period if no actions are taken.
- 2) *Security of supply.* Europe is increasingly becoming more dependent on imported fuels. A continuation of existing trends will imply that the present import share of 50% will increase to approx. 65% in 2030. This implies a high vulnerability of the energy system, e.g. in relation to terrorism.

In facing these challenges the EU member states by 2008 adopted long term targets in three different areas of energy policy: 1) The EU has agreed on a binding reduction of greenhouse gases of 20% by 2020 compared to 1990; this target can be raised to 30% subject to the conclusion of binding international climate change agreements. 2) A mandatory target for the development of renewable energy sources; by 2020 20% of final energy demand in EU has to be supplied by renewable technologies as wind power, solar and biomass. 3) A voluntary agreement on energy efficiency with the objective of saving 20% of EU energy consumption by 2020 compared to a reference projection. Finally, EU has a target of achieving a share of 10% of renewable sources including biofuels in transport by 2020. In Europe the achievement of these targets requires a development which is driven both by national and EU policies.

As part of the EU Denmark has a commitment of reducing its emissions of greenhouse gases by 21 percent on average in the period 2008-2012 as compared to 1990. For more than a quarter of a century Denmark has developed a environmentally strong profile with regard to the development of the energy sector and since the beginning of 1990s the problem of Climate Change has been the most important driving factor behind the Danish energy policy. However, Denmark is one of those countries that want to go even further.

In 2008 the Danish Prime Minister announced a vision of a Denmark being independent of fossil fuels in the long term time perspective, not only improving our security of energy supply but also significantly reducing our GHG-emissions. This vision led to the establishment of the Danish Commission on Climate Change policy which by September 2010 launched its report, stating that by 2050 a Danish energy system independent of fossil fuels is achievable without excessive costs to society.

In February 2011 the Danish Government launched its follow-up report; the official plan entitled Energy Strategy 2050. The Energy Strategy suggests a number of policy initiatives for phasing out fossil fuels in the long term. Naturally, such a long term development requires significant changes in the structure of the energy system, as well as a continued use of strong policy measures.

This new policy relying to an increasing degree on renewable sources are going to change the Danish and the European energy systems radically within the next decade. Energy technologies based on variable sources, especially wind power and photovoltaics, are expected to have a large role to play in the future energy supply. New emerging technologies as heat pumps and fuel cells might be important as well.

Energy consumption in the existing building stock in Denmark accounts for approx. 40% of total energy consumption. The Danish energy system is today characterised by a very diversified and distributed energy generation based upon three major national grids; the power grid, the district heating grid and, finally, the natural gas grid. The combined utilization of these grids has implied that we have a highly efficient supply system with a high share of combined heat and power. Approx. 60% of the heating needs are supplied by district heating and the residual 40% is equally covered by oil and natural gas furnaces. The last-mentioned ones account for approx. 20% of total energy consumption in Denmark.

If we want to develop an energy system being independent of fossil fuels in the future, this will require new higher standards for energy efficiency and a radical introduction of new and renewable energy technologies, all together implying that buildings in the future might act as prosumers that is both demanding and producing energy. In this project the effect of implementing energy savings and/or individual energy production is evaluated in a possible future Danish energy system of 2030.

Thus, the close interactions between new emerging and/or renewable technologies being implemented in single-family houses and strong energy conservation initiatives are at the core of this report. We look at the overall consequences for the energy system of introducing new technologies as photovoltaics and heat pumps in combination with major energy conservation measures. A number of energy system scenarios are prepared based on technical simulations for single-family houses carried out by the University of Aalborg. The study focuses on houses built between 1961 and 1972 as houses from this time constitute a large part of the single family houses and as they have a high energy saving potential.

2 Scenarios for the Danish Energy system

The aim of this project is to evaluate the possible energy and environmental consequences of the implementation of energy conservation in combination with the introduction of new and renewable energy technologies, especially in the existing building stock. To do so a number of national scenarios are analysed with the Energy systems model, Stream. These scenarios are based on a number of detailed technical simulations for single family houses carried out by Aalborg University.

It should be observed that only single-family houses build between 1961 and 1972 are handled in the technical simulations from Aalborg University. Thus this segment of the building stock is also the starting point used in the overall energy systems calculations.

2.1 Scenarios

In order to evaluate the impact of energy savings and production in single family detached houses, a number of technological parameters (energy saving measures and energy generation technologies) served as a baseline to simulate the building's electricity and heating demands. These parameters were varied according to the respective energy strategy (saving, production or a combination thereof). Building related parameters used to simulate energy savings are

- Mechanical ventilation
- Windows
- Exterior walls
- Floor
- Roof

Energy generating technologies used in the production scenarios are

- Solar PV
- Solar heating panels
- Heat pumps (ground source)

Saving measures and technologies are allocated to the individual scenarios in Table 1. The following scenarios are applied to both buildings with access to district heating (referred to as district heating sector) and those with individual heating systems (individual heating sector). Heat pumps are only used in the individual heating sector, where they are assumed to cover the entire heating demand.

Maximum savings scenario

Here, a high level of insulation of exterior walls, floor, roof and windows was assumed as well as mechanical ventilation. These measures lead to a significant reduction in the heat demand but do not affect the electricity demand. Any deviations in the electricity demand between savings scenarios and the base case are due to the stochastic variability inherent to the demand simulation approach (1).

Maximum production scenario

In this scenario, no energy saving measures were employed but heat and electricity are generated by using solar heating and solar PV panels. In the data provided by Alborg University, all buildings of the individual heating sector are assumed to use heat pumps. However, the individual heating sector will be assessed with and without the use of heat pumps in the course of this report.

Maximum savings plus production scenario

In this case, the above mentioned scenarios were combined in order to achieve a maximum amount of energy savings and to use solar PV and heating panels to produce extra energy.

2.2 The base case

The base case serves as baseline which the scenario results are compared to. In the base case, no measures of energy savings or production are introduced. Otherwise the building is of the same size and type (157 m², detached house built between 1961 and 1972).

Table 1 illustrates energy savings measures and production technologies of the respective scenarios. Heat pumps are not included in the table, since the savings and production scenarios will be analysed in the individual heating sector both with and without the use of heat pumps.

Table 1: Energy savings / production measures of the various scenarios

Category / technology	Maximum savings	Maximum production	Maximum savings + production	Base case
Mechanical ventilation	yes	no	yes	no
Windows	high level of insulation	low level of insulation	high level of insulation	low level of insulation
Exterior walls	high level of insulation	low level of insulation	high level of insulation	low level of insulation
Floor	high level of insulation	low level of insulation	high level of insulation	low level of insulation
Roof	high level of insulation	low level of insulation	high level of insulation	low level of insulation
Solar PV	no	44.3 m ² / 5.5 kW _{peak}	44.3 m ² / 5.5 kW _{peak}	no
Solar heating	no	6.6 m ² / 4,33 kW (nominal), 400 l storage tank	6.6 m ² / 4,33 kW (nominal), 400 l storage tank	no

For each scenario different heat and electricity demand profiles were simulated (1). For the detailed description of the demand profiles see section *Heat and Electricity Demand* below. Energy savings and production achieved by applying the various scenarios in both the district heating and individual heating sector are depicted as percentages of a base case demand in Figure 1. They are calculated by subtracting the sum of the annual profiles (electricity and heat) of the scenarios from the sum of the base case profiles and dividing by the sum of the respective base case profiles.

The increase in the electricity demand in the individual heating sector is due the fact that the profiles were created assuming the use of heat pumps to cover the heating demand. Originally, the profiles for the individual heating sector from Aalborg University do not include heating demands. All the heating demand is reflected in an increased use of electricity by heat pumps. In this report, the heat demand in the individual sector is assumed to be equal to that of the district heating sector to be able to compare effects. The actual percentages are 49% for District heating and 51% for individual heating. The reasons and arguments for this assumption are explained in section *Heat and Electricity Demand*. Due to this assumption, the magnitudes of heat savings depicted in Figure 1 are equal for the district heating and individual heating sector.

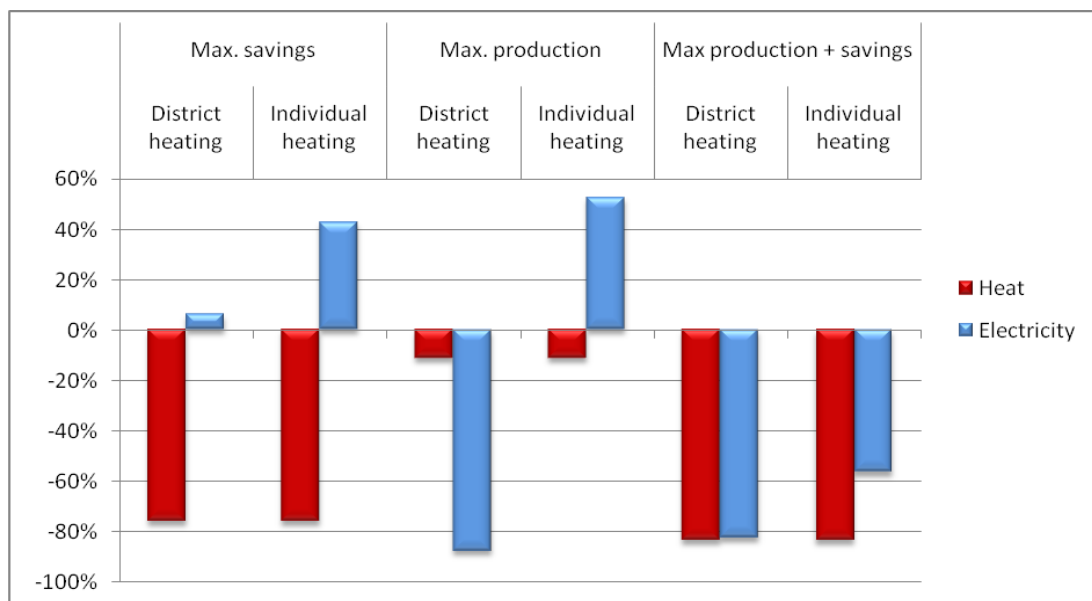


Figure 1: Heat and electricity savings in %, achieved by respective scenarios in the district heating and the individual heating sector. Heat pumps are used in the individual sector.

3 Modelling and data

3.1 The STREAM-model

STREAM is an energy system modeling tool which balances energy demands and supplies within the time frame of one year and delivers results on energy production, fuel consumption (resource utilization), emissions and costs. It is typically used for predictive or explorative analysis of national energy systems but not capable of system optimization. A reference scenario is devised by the user. The reference scenario is set up to predict the state of development of an energy system at a certain time in the future, usually based on current trends. The model scenario, placed in the same year as the reference, includes the intended changes in the system. Comparing the two scenarios gives an idea of the impacts of the implemented changes on the system.

STREAM consists of three interacting excel spreadsheets, namely the energy savings model, the energy flow model and the duration curve model. The data flow between the models is depicted in Figure 2.

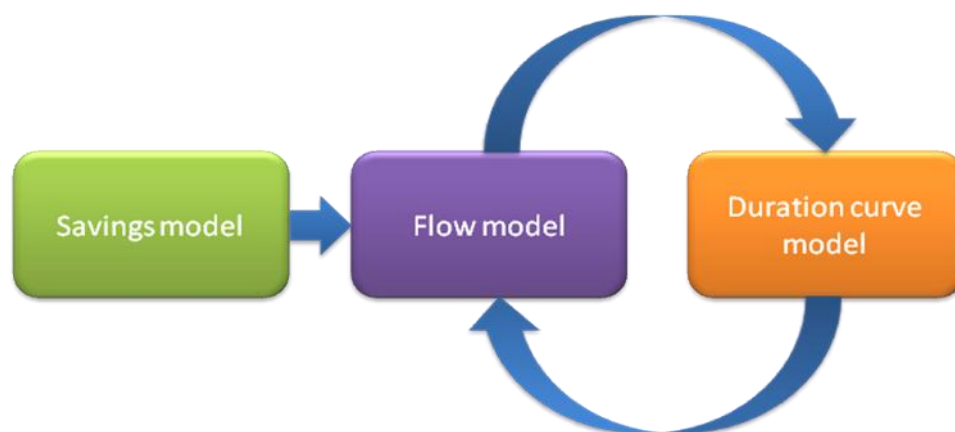


Figure 2: Interaction of the individual models in STREAM

Annual energy service demands are inserted into the savings model. These demands are adapted to the requirements and conditions of the scenarios and serve as an input to the flow model. In the flow model, the conversion of energy by various technologies and the extent to which each technology is deployed, are determined. The required energy production, given by the flow model, is passed to the duration curve model, where the load hours are determined for the various technologies. The output of the duration curve model is returned to the flow model. Installed capacities and required energy production are matched by iterative repetition of this operation.

The STREAM model scenarios presented in this document are based on data provided by the University of Aalborg (1) and the 2009 version of the DG-TREN forecasts for Denmark for the year 2030(2). The project partners from the University of Aalborg provided a number of

electricity and heat demand profiles of single family homes (157m² of floor area), built between 1961 and 1972, with standardised building characteristics. Buildings of this type and period constitute 11% of all Danish residential and commercial buildings by floor area (see *Appendix*). The demands are simulated for dwellings with access to a district heating system as well as for such with individual heating, which are assumed to employ heat pumps. Within those two domains, demand profiles for three different energy strategies were developed, namely an energy savings and an energy production strategy, as well as a combination of both. Energy savings are achieved exclusively by higher building standards, such as optimized insulation. Energy production refers to the utilisation of solar energy by employing PV and solar heating technologies.

Ten STREAM models were created to simulate the implementation of the various energy saving strategies in the district heating and the individual heating sector with and without the use of heat pumps. For each scenario, individual savings and flow models were produced, taking into account the various levels of energy savings and production. In the district heating scenarios, individual duration curve models simulate the time dependence of the heat savings. All scenarios are compared against a common reference scenario, which is based on data of the 2009 DG-TREN report (2). The following section serves to illustrate the implementation of data into the various models of STREAM for each scenario.

Please note that the individual heating scenarios without the use of heat pumps were computed in the same way as the heat pump scenarios discussed below, with the only difference that heat demands and demand reductions are not attributed to heat pumps, but divided up equally on the remaining heating fuels: oil, natural gas, biomass, coal and electric space heating. Therefore, no separate sections for the computation of the individual heating models excluding heat pumps are included in the following.

3.2 Model implementation

The implementation of scenarios and simulation data into the STREAM model is described in the following sections for the district heating areas and the individually heated areas. The overview can be found in Table 2.

Table 2: Calculation of total energy savings and production in district heating and heat pump areas

	District heating (D.H.)			Individual heating (I.H.)		
Strategy	Max savings	Max production	Max prod. + sav.	Max savings	Max production	Max prod. + sav.
Heat savings	$H_{Base}-H_{Sav}$	-	$H_{Pro}-H_{Pro+Sa}^*$	as D.H. _{Sav}	-	as D.H. _{Pro+Sa}
PV	-	$P_{Base}-P_{Pro}$	$P_{Base}-P_{Pro+Sa}$	-	as D.H. _{Pro}	as D.H. _{Pro+Sa}
Solar heat	-	$H_{Base}-H_{Pro}$	$H_{Base}-H_{Pro}$	-	as D.H. _{Pro}	as D.H. _{Pro}

* This expression is derived from the difference between the reduced heat demand of the production + savings scenario ($H_{Base}-H_{Pro+Sa}$) and the solar heat production of the production scenario ($H_{Base}-H_{Pro}$):

$$Heat\ savings_{Pro+Sa} = (H_{Base}-H_{Pro+Sa}) - (H_{Base}-H_{Pro}) = H_{Pro}-H_{Pro+Sa}$$

Fejl! Henvisningskilde ikke fundet. summarises the calculation of heat savings, PV and solar heat production for each scenario. H is the total heat demand (space heating plus hot water), P is the electricity demand and indices refer to the different energy strategies (maximum savings, production and production + savings) or to the base case. Depending on the use of the data in the STREAM model, the calculations of **Fejl! Henvisningskilde ikke fundet.** are either performed for hourly annual demand profiles (which is the case for calculating time dependant heat savings in the district heating sector) or for total annual demands, i.e. the sum of the profiles.

3.2.1 Maximum savings

District heating

Heat savings in this scenario were implemented in both the savings and the duration curve model. The total annual decrease in district heating demand was subtracted from the domestic district heating demand in the savings model. In order to take into account the time dependence of the savings in district heat, the savings profile, which is calculated according to **Fejl! Henvisningskilde ikke fundet.**, is subtracted from the district heating profile in the duration curve model. This calculation was included in the up-scaling operation in the duration curve model, where the hourly district heating profile, as provided by an individual district heating supplier, was scaled to meet the annual national demand. Only the duration profile is changed whereas the total demand is maintained, as this is provided by the savings model. See equation (4):

$$D_i = \frac{H_i}{\sum_{i=1}^t H_i} \cdot \left(D^{total} + \sum_{i=1}^t S_i \right) - S_i$$

Where $t = 8760h$, D_i is the national district heating demand in hour i , H_i is the hourly district heat production of an individual supplier, D^{total} is the annual national district heat demand and S_i are hourly savings.

Heat pumps

For all heat pump scenarios, heating supplied by heat pumps is assumed to be equal to the heat demand of the corresponding district heating scenario. This assumption is necessary, since no heat demand profiles were provided for heat pumps. It is not possible to calculate the heat pump production directly from the electricity demand, since no compliant COP factors are given (merely a COP range between 3 and 4). However, the assumption is reasonable, since the building characteristics of corresponding scenarios are identical.

The reduction in domestic heating demand is assumed to substitute an average of all fuels, meaning that the demand reduction was divided over all remaining residential heating fuels according to their relative shares of the total demand in the savings model. The heating supplied by individual heat pumps was then added to the fuel mix while reducing each of the remaining fuels by the corresponding fraction, so that the overall demand remains constant. From these newly calculated demands, the relative shares of the various fuels are calculated anew. These shares constitute the new domestic heating mix, changed by the reduced demand and increased individual heat pump utilization. In the description of the data profiles from Aalborg University, the COP factor for individual heat pumps is stated to vary between 3 and 4. Here, it is assumed at 3, to be consistent and conservative.

No further changes were applied to the flow or duration curve model in this scenario. There, the increased electricity consumption will be covered by a mix of the electricity producing technologies, except for municipal waste, wind and hydro power, for which the production is assumed to remain constant.

3.2.2 Maximum production

District heating

In this scenario, solar heating production is, in fact, equivalent to a reduction of the district heating demand. Therefore, solar heating is simulated as heat savings in section *Maximum savings – District heating* and the same operations are performed in the savings and duration

curve model. The solar heating production profile is obtained according to **Fejl! Henvisningskilde ikke fundet..**

Solar PV production is assumed to substitute an average of all fuels for electricity production, except for wind, hydro and municipal waste, as these plants are assumed to operate at full load, with top priority, when implemented. The solar PV profile is calculated according to **Fejl! Henvisningskilde ikke fundet.** and the yearly total is the sum of the profile. The total annual PV production is subtracted from the remaining fuels according to their shares of the total production in the flow model. The new shares of fuels are then calculated from these reduced demands.

Heat pumps

The annual solar heating production is obtained according to **Fejl! Henvisningskilde ikke fundet..** The heating demand (equal to that of the *Maximum production – District heating* scenario) is covered by heat pumps, in combination with the solar heat. An average of the remaining fuels is substituted, as described in section *Maximum savings – Heat pumps*.

Solar PV production is implemented in the same manner as described in section *Maximum production – District heating*.

3.2.3 Maximum production plus savings

District heating

Heat savings and solar heating production cannot be distinguished by means of the heat demand profile and are therefore both treated as heat savings (see **Fejl! Henvisningskilde ikke fundet.**). The annual demand reduction in the savings model and the change in the hourly district heating demand in the duration curve model are computed as described in sections *Maximum savings – District heating* and *Maximum production – District heating* respectively.

Solar PV production is determined according to **Fejl! Henvisningskilde ikke fundet.** and implemented in the flow model as described in section *Maximum production – District heating*.

Heat pumps

The heating demand covered by heat pumps is equal to that of the scenario *Maximum production plus savings – District heating*. Savings and production profiles are obtained according to **Fejl! Henvisningskilde ikke fundet..** Heat savings are implemented in the savings model as described in section *Maximum savings – Heat pumps*. Solar heating production and,

subsequently, heat pump production are computed in the same manner as in section *Maximum production – Heat pumps*.

Solar PV production is included in the flow model as described in section *Maximum production – Heat pumps*.

District heating + heat pumps

In this scenario all buildings of the investigated type are regarded, meaning that the full potential of savings and production is calculated for both the district heating and the heat pump sector.

The demand covered by heat pumps corresponds to the heat demand of the scenario *Maximum production plus savings – District heating* but scaled to the full potential of the heat pump sector, as described in section *Data* below (i.e. from 49% of the single family homes of 1961-1972 to 51%). Savings and production profiles are determined according to Table 3. Total annual heat savings in the heat pumps domain are subtracted from the residential heating demand in the savings model in the same way as in section *Maximum savings – Heat pumps*. Subsequently, solar heating and heat pump production are implemented as described in section *Maximum production – Heat pumps*. Heat savings in the district heating sector are implemented in both, the savings model and the duration curve model, as described in section *Maximum savings – District heating*. PV production is added in the flow model as previously described.

Table 3 **Fejl! Henvisningskilde ikke fundet.** gives an overview of how energy savings and productions (applicable to hourly profiles as well as annual totals) are calculated, using the same terminology as described for Table 2 **Fejl! Henvisningskilde ikke fundet.**. Note that the scaling factor f remains the same for the district heating area but is adjusted to cover the full scope for the individual heating sector. This is done since the fraction of buildings with individual heating is slightly larger (51%) than that with access to district heating (49%). The calculations displayed in Table 3 **Fejl! Henvisningskilde ikke fundet.** are based on already up-scaled energy demands (see equation (3)). In the case of individual heating, the demands are therefore divided by the original scaling factor f_{DH} (which gives the demand of all buildings of the investigated period) and subsequently multiplied with the factor f_{HP} , which gives the demand for all buildings with individual heating.

Table 3: Calculation of energy savings (hourly profiles and annual totals) in the district heating and the heat pumps sector

Energy savings profiles: D.H. + I.H. Max. production + savings		
	District heating	Individual heating
Heat savings	$H_{Pro} - H_{Pro+Sav}$	$(H_{Pro} - H_{Pro+Sav}) \cdot \frac{f_{HP}}{f_{DH}}$

PV	$P_{Base} - P_{Pro+Sav}$	$(P_{Base} - P_{Pro+Sav}) \cdot \frac{f_{HP}}{f_{DH}}$
Solar heat	$H_{Base} - H_{Pro}$	$(H_{Base} - H_{Pro}) \cdot \frac{f_{HP}}{f_{DH}}$

3.3 Heat and electricity demand

The objective of this project is to assess the impacts of the different energy strategies on the national energy system for buildings with and without access to district heating. In order to simulate maximal effects, the demand profiles for maximum savings, maximum production and maximum savings plus production, for both the district heating and the individual heating domain, were used as the basis for the STREAM scenarios. Annual electricity and heating demand data were provided for one individual building in the following manner.

Electricity demand (1):

$$P = \sum_{i=1}^t P_i$$

Heat demand (2):

$$H = \sum_{i=1}^t H_i$$

Where $t = 8760$ h, P is the total annual electricity demand, P_i the electricity demand in hour i , H is the total annual heating demand (space heating plus hot water) and H_i the heating demand in hour i .

Figure 3 and Figure 4 give examples of such profiles, namely the electricity and heat demand of both the district heating and the individual heating sector in the maximum savings scenario. As can be seen from Figure 4, no heat demands are given for the individual heating sector, since the heat is assumed to be supplied entirely by heat pumps. The power required for the heat pumps is included in the respective electricity profiles.

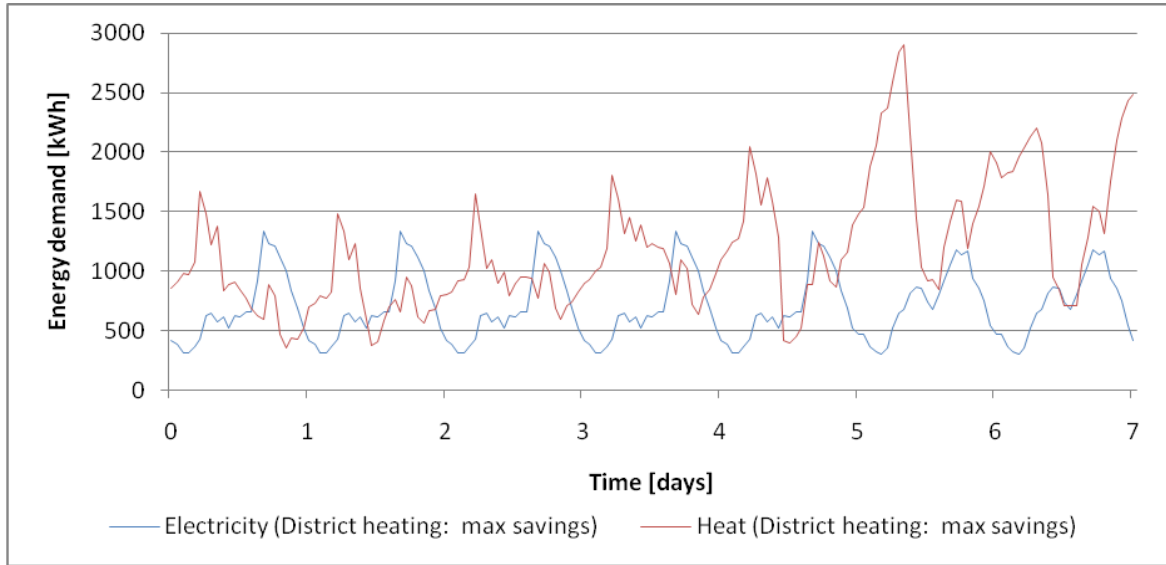


Figure 3: Hourly electricity and heat demand profiles (maximum savings scenario) of one single family home in the district heating domain for the period of one week.

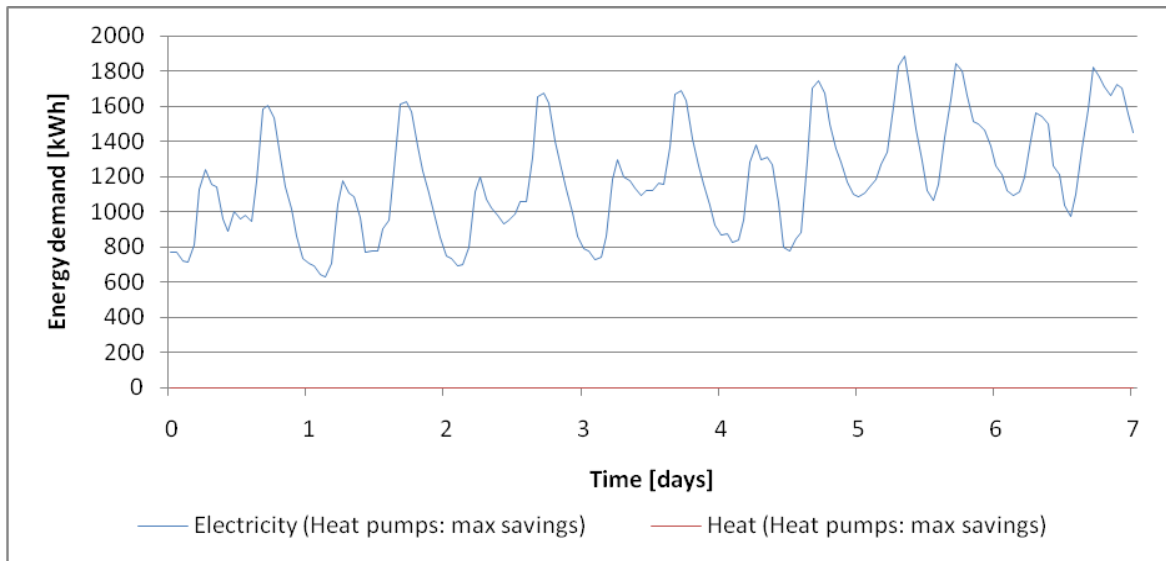


Figure 4: Hourly electricity and heat demand profiles (maximum savings scenario) of one single family home in the individual heating domain with the use of heat pumps for the period of one week.

The demands were up-scaled to a national level according to (3):

$$E = \sum_{i=1}^t \frac{E_i}{A_{ind}} \cdot A_{total} \cdot f$$

Equation (3) can be applied to both electricity and heat demand (E), A_{ind} is the floor area of one individual building, A_{total} is the floor area of all buildings of the investigated type in Denmark and f is the fraction of those buildings which have access to district heating. $f = 49\%$ for the district heating and 51% for individual heating sector. In order to allow for a direct comparison of the results of both domains (district and individual heating), the fraction $f = 49\%$ is also used to calculate demands for dwellings with individual heating.

The net energy savings and production of the various energy strategies were calculated by subtracting the heat and electricity demand profiles of the various scenarios from those of a so called base case, which represents the same type of building without any measures of improvement. In the data from Aalborg University, only the net demands are illustrated. Hence, assumptions regarding the correlations of the different cases are undertaken.

Energy production from PV is assumed to be equal to the difference between the electricity demand of the base case and that of the production scenarios. Equivalently, solar heating production is assumed to be equal to the heat savings in the production scenarios. However, in the maximum savings plus production scenarios, heat savings as such cannot be distinguished from solar heating production, solely by the heat demand profiles available. In those cases, solar heating production is assumed to be equal to the solar heating production of the corresponding maximum production scenario. This assumption is reasonable, since the building characteristics are equal among corresponding scenarios. In the case of individual heating, no heating demands are provided, since it is assumed that all the heat is supplied by heat pumps. Moreover, PV production cannot be determined simply from electricity demands, since those include electricity used for heat pumps. Therefore, heat savings, PV and solar heating production are assumed to be equal to those of the corresponding district heating scenarios. Again, the assumption is reasonable since there is no difference in the characteristics of buildings or technology.

Total annual demands, calculated according to equation (3), are listed in Table 4. These are the scaled sums of the respective profiles provided by Aalborg University. Again, it should be noted that, in the case of individual heating, all heat demands are assumed to be covered by heat pumps, i.e. utilization of electricity. Hence, the value of zero heat demand in the maximum savings strategy. Here, the production of solar heat is not shown, since it would lead to a negative figure in individual buildings (Table 4). Electricity demands are of course increased by the use of heat pumps.

Table 4: Total yearly energy demand

Energy demands [PJ]								
Energy strategy	Base case	Max. savings		Max. production		Max production + savings		Reference (national demand 2030)
Domain	(1961-1972)	District heating	Ind. heating	District heating	Ind. heating	District heating	Ind. heating	
Heat demand	9.2	2.2	0	8.2	0	1.5	0	242.8
Electricity demand	2.2	2.3	3.1	0.3	3.3	0.4	0.9	176.9

Energy savings potentials relative to the total reference are summarised in Table 5. The relative savings are calculated by subtracting the scenario demands from the base case and dividing by the reference demands. The reference is based on the DG-TREN forecast for 2030 and represents the annual national heating and electricity demands in Denmark (2).

Table 5: Energy savings potential relative to the national reference

Energy savings [%]						
Strategy	Max. savings		Max. production		Max production + savings	
Domain	District heating	Individual heating	District heating	Individual heating	District heating	Individual heating
Heat	3%	4%	0%	4%	3%	4%
Electricity	0%	-1%	1%	-1%	1%	1%

In addition to the above described scenarios, the total maximum energy savings potential was calculated. This is the maximum potential of energy savings that can be achieved in the investigated domain of dwellings (all single family homes of the period 1961 – 1972) by applying both the energy savings and production strategy in combination with the use of heat pumps. In the following, this scenario will be referred to as **Total Savings Potential**. To calculate energy demands in the heat pump domain, as part of the total savings potential, the factor f in equation (3) is substituted by the fraction of homes with individual heating. To calculate energy savings the base case demand was up-scaled with $f = 1$, since the range of investigated buildings

stretches over both, the district heating and individual heating domain. Total demand and relative savings are listed in Table 6. The total base is the entire energy demand of all single family homes (period 1961-1972) without any energy saving or production measures. The total demand is the entire energy demand of those buildings with application of the maximum savings + maximum production strategy and the use of heat pumps. The total savings potential is the fraction of energy savings (total base – total demand) and the national reference demand (See Table 3).

Table 6: Total demand and maximum energy savings potential for district heating plus heat pump areas

Total energy savings potential: D.H. + I.H. Max. production + savings			
	Total base [TJ]	Total demand [TJ]	Total savings potential
Heat	19004	413	8%
Electricity	4441	1370	2%

4 Results and Discussion

4.1 Changes in energy demand

By comparing total annual demands of the investigated housing sectors (as provided from Aalborg University (1)), changes in energy demand in the various sectors, achieved with different strategies, can be assessed. These potentials are depicted in terms of changing demands related to the housing sector and related to the national demand in Figure 5 and Figure 6 respectively.

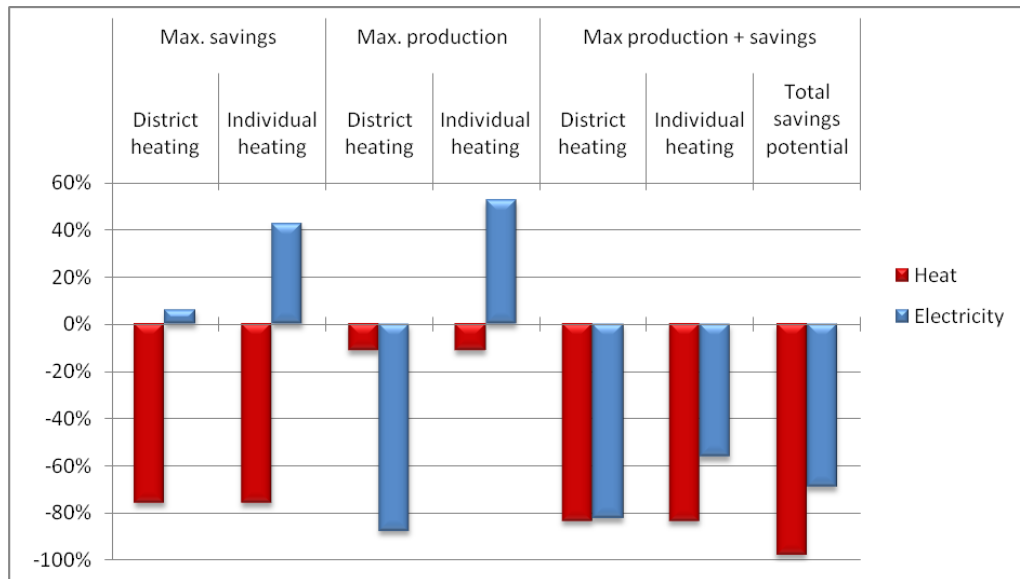


Figure 5: Change in demand with respect to the single family homes from period of 1961 to 1972

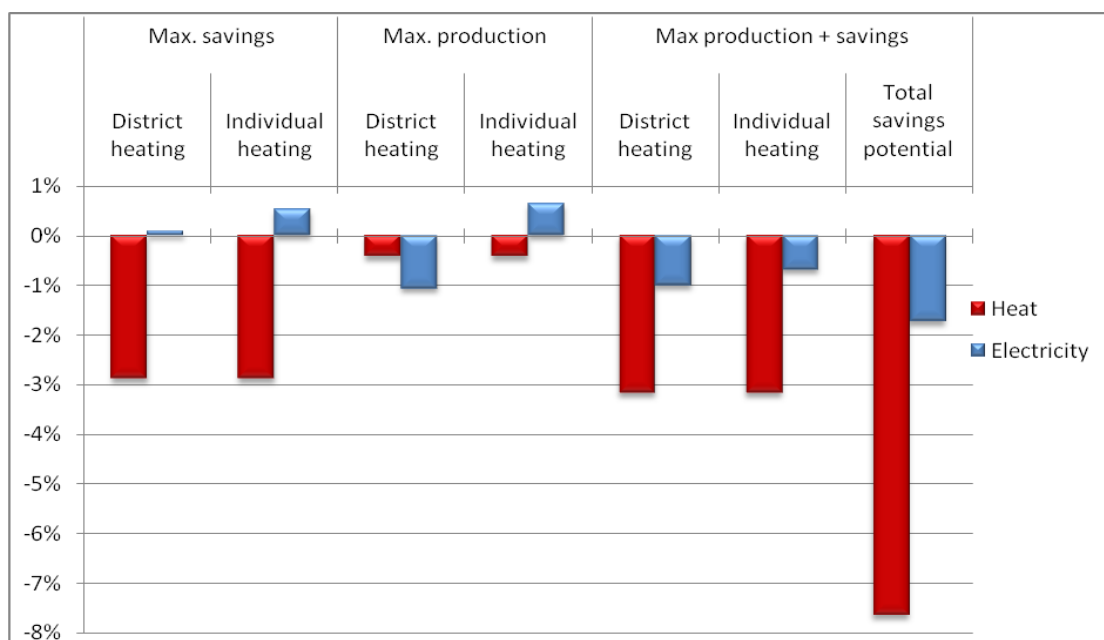


Figure 6: Change in demand with respect to the national demand

It must be noted that, in contrast to the demands listed in Table 4, the heating demands for houses employing heat pumps are not set to zero, but assumed to be equal to the heating needs of the corresponding district heating strategy. Logically, houses with heat pumps still have a heating demand, even though this is satisfied by the use of electricity. When looking at Figure 5 and Figure 6 it should be born in mind that, in the case of heat pumps, the entire heating demand (red column) is covered by the electricity demand displayed in the same figure (blue column). Also note that in the above figures the heat pump sector is equivalent to the individual sector, as discussed earlier.

From Figure 5 it becomes clear that employing the **energy savings strategy** leads to heat savings of over 75% in the investigated housing sector. This is true for both district heating and heat pump areas, since building characteristics and total floor area are equivalent. Using heat pumps, the remaining heat demand can be covered by an increased electricity use of roughly 40%. The slight increase in electricity demand in the district heating sector is due to stochastic variations between the base case and the scenario case, caused by the applied modeling method (1). On a national level, potential heat savings are just below 3% and the increase in electricity use for heat pumps about 0.5% (see Figure 6).

Looking at the **energy production section** in Figure 5, it is evident that a maximum electricity saving potential of >85% can be achieved in the district heating sector by solar PV production. The same amount of solar PV production is assumed for the individual heating (heat pump) sector. The lack of heat saving, however, leads to a greater increase of electricity demand (>50%) than in the savings scenario since larger amounts of heat must be provided by the heat pumps. A similar situation can be observed for solar heat production; the lack of heat savings leads to an overall significantly smaller decrease in heat demand (roughly 10%) than in the savings scenario, despite the additional solar heat produced. National heat demands are only reduced by about 0.4% and electricity demands are increased in heat pump sector by a mere 0.6% and reduced in the district heating sector by only 1% (see Figure 6).

Obviously, the largest saving potentials can be achieved by **combining the energy savings with the energy production strategy**. This could yield total heat savings of >80% in both sectors, electricity savings of >80% in the district heating, and >55% in the heat pump with respect to the housing segments (see Figure 5). On a national level, potential savings in the district heating and heat pump area are on the scale of 1% and 0.7% for electricity and 3% heat respectively (see Figure 6).

The total savings potential combines the energy savings achieved in the production plus savings scenarios of both sectors and extends the scope for the individual heating area (roughly 1% of additional floor area) to cover the entire scope of 11% of total residential and commercial floor space area in Denmark. Additionally, the heat demand of the individual heating area which is supplied by heat pumps is in this scenario shown as part of the reduced heat demand. This leads to a very low heat demand and an increased electricity demand in the individual heating area. Consequently, demands are decreased by about 98% of heat and 70% of electricity within the housing domain (Figure 5) and roughly 8% of heat and 1.7% of electricity on a national level (Figure 6).

4.2 National energy consumption

The STREAM model is used to assess the impact of the above explained strategies on the Danish energy system in terms of changes in national energy consumption, fuel usage and GHG emissions. In order to evaluate the benefits of using heat pumps in the individual heating sector, two distinct scenarios are devised (individual heating sector with and without heat pumps) for each energy strategy.

4.2.1 Fuel use for electricity and heat

Figure 7 shows the reductions in fuels used for electricity and heat production. When applying the **savings strategy** in the district heating sector, fuels for heating can be reduced by up to 8.6%. Fuel demands for electricity are raised (by 0.4%) due to an increasing share of condensing power (from 40% to 43%), which implies lower total efficiencies. The difference in electricity savings in the individual heating sector with and without heat pumps is negligibly small as the increase in electricity use for heat pumps is compensated by a decrease in electricity use for electric space heating. As discussed above, the savings are mainly due to the lower heat demand, which reduces the load hours of heat pumps and electric space heating. The share of condensing power in the individual heating sectors is almost the same as in the reference.

Due to the lack of heat savings, much smaller reductions in fuel use are obtained in the **maximum production** scenarios. Solar heating and PV cannot compensate for the heat losses. Even a small increase in the fuel demand for heat is noticeable in the individual sector without heat pumps (0.3%). The increase is negligible when using heat pumps. Less net electricity savings are obtained due to the use of heat pumps. The shares of condensing power vary by a maximum of 0.7% between the different scenarios, where the largest share is obtained for district heating and the smallest using heat pumps.

Again, **combining the savings and production strategies** yields the largest reductions in energy demand. In the district heating sector, additional PV compensates for increased electricity fuel demands at a share of condensing power of 43%. The slight increase in fuels for heating in the individual sector (with and without heat pumps) can be attributed to a reduction of the share of condensing power to values around 38.5%. This indicates a higher rate of CHP production, meaning that a larger amount of fuel is attributed to the generation of heat.

The total savings potential summarizes both positive and negative impacts of the various energy strategies, as discussed earlier.

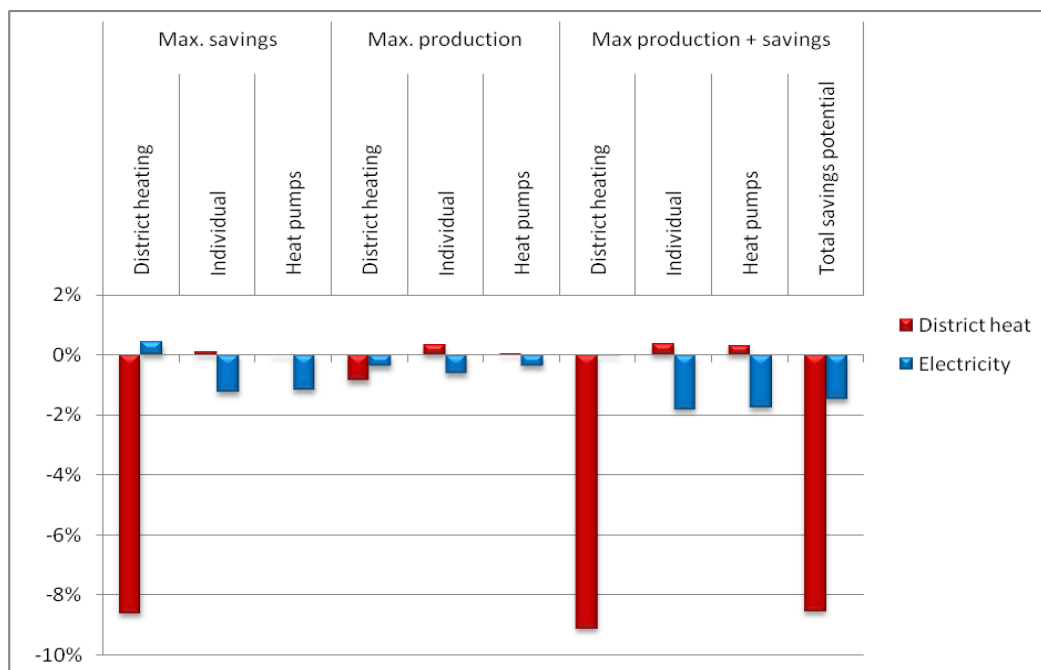


Figure 7: Change in fuel consumption for electricity and district heat production with respect to the national consumption

4.2.2 Fuel use attributed to technologies

In order to elucidate the correlation between changes in fuel usage on a national level and energy savings or production in housing, the composition of the fuel mix used in the residential sector (reference scenario) (Figure 8), for district heating boilers (Figure 9) and for electricity production (Figure 10) is illustrated for the 2030 reference scenario.

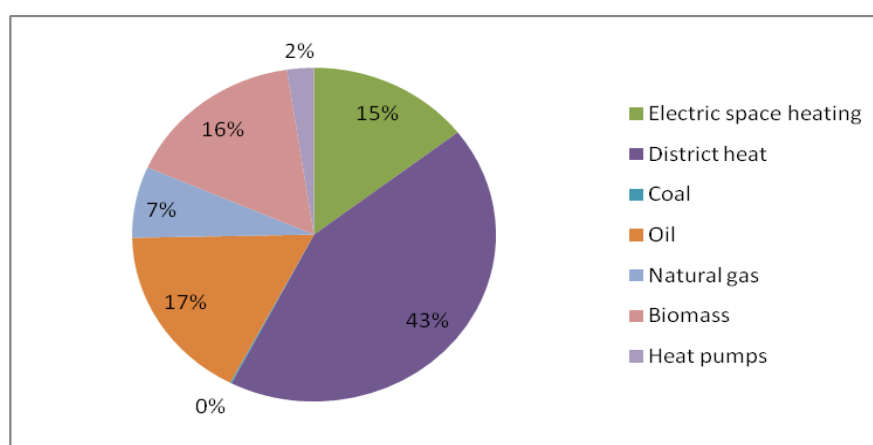


Figure 8: Fuel use for space heating in the residential sector, reference scenario

The main source of space heating is district heating with oil, biomass and electric space heating (apart from heat pumps) coming in next as shown in Figure 8.

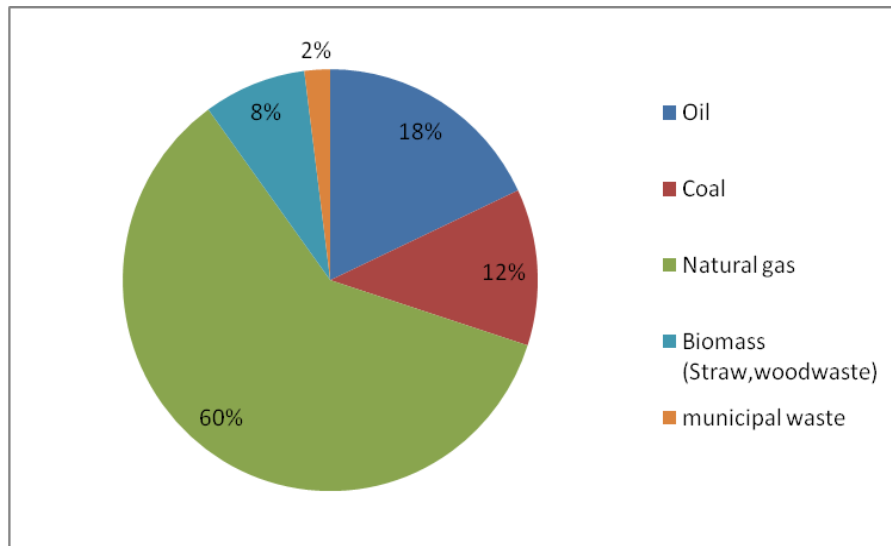


Figure 9: Fuel use for district heating boilers

By far the main fuel used to produce district heating is natural gas followed by oil and coal as shown in Figure 9.

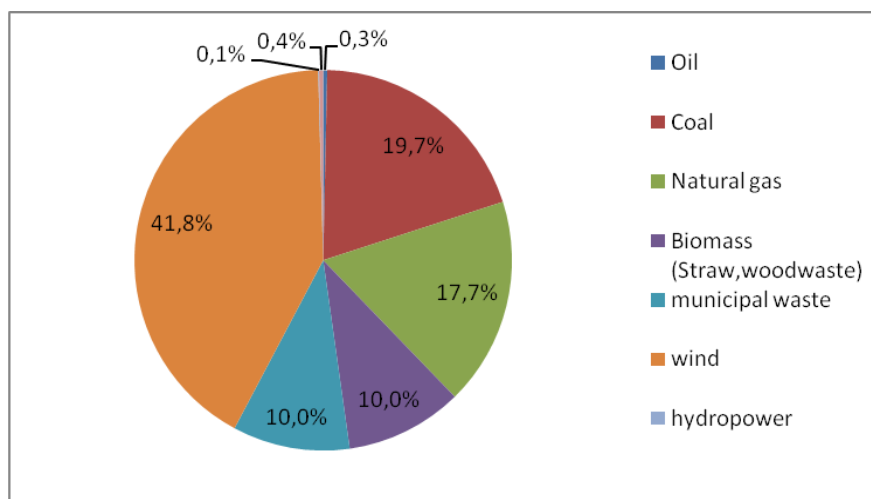


Figure 10: Fuel mix for electricity generation

The main energy source used to produce electricity is assumed to be wind. Second comes coal and then natural gas as illustrated in Figure 10.

Figure 11 displays the change in national fuel usage in [PJ]. Again, fuels for wind, hydro power and municipal waste are maintained at constant values with regard to the reference, since they receive top generation priority.

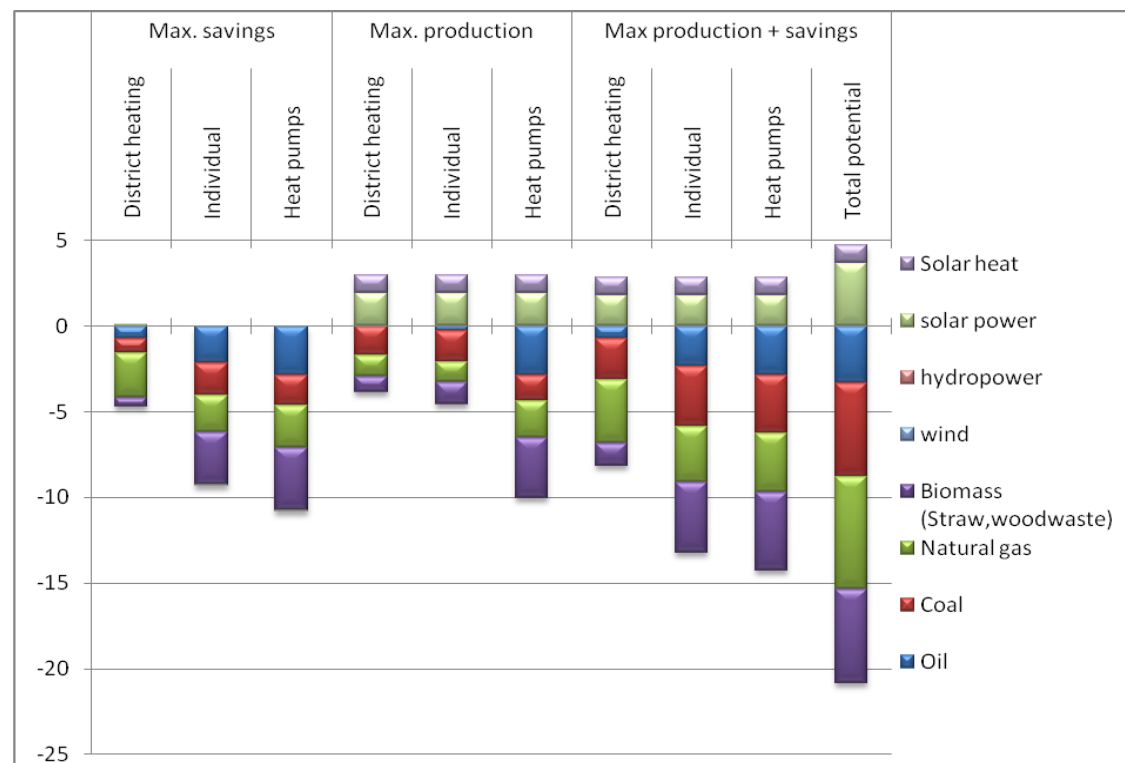


Figure 11: Changes in total gross energy consumption [PJ] divided on fuels used by different technologies

In the **savings scenario** of the district heating sector, the predominant fraction of fuel savings can be attributed to the reduction of natural gas (see Figure 11). This is due to the fact that natural gas constitutes 60% of the district heating fuels (see Figure 9). The reduction of which is the prime result of the maximum savings strategy. Oil and coal are reduced to a lesser extent, again related to the corresponding fractions of the fuels – 18% and 12%, respectively – used in district heating boilers. When looking at savings in the individual sector, biomass and oil make up the largest fraction of fuel savings, followed by natural gas and coal. Oil and biomass constitute 17% and 16% of the fuels used for space heating and are significantly reduced by the implemented heat savings. Natural gas usage is reduced both by direct savings of space heating fuels (7% of space heating) and by the more efficient use of electricity achieved by employing heat pumps. The latter also applies to coal. Natural gas and coal contribute to electricity production with 18% and 20% respectively in the scenario. Overall, the use of heat pumps leads to additional savings in fuel consumption of 1.5 PJ.

Fuel savings achieved in the **production scenario** are very similar among the district heating and the individual sectors. This is due to the fact that solar heating and PV production is equal in all sectors, leading to an equal decrease in fuels for electricity production. Slightly larger savings in the individual sector can be accredited to higher efficiencies in electricity production at lower

shares of condensing power. The production scenario reveals the net benefits (without savings) of implementing heat pumps. Even at a conservative average COP estimate of 3, the increased efficiency leads to an additional decrease in total fuel usage of ~6 PJ when comparing to the district heating and individual heating sector.

The **combination of savings and production scenarios** leads to an accumulation of the above described effects, maximizing the total savings. However, in the case of heat pumps, the fuel savings achieved in the two separate energy strategies do not directly add up and the benefits of accumulating both scenarios do not appear as large as one might anticipate. This is due to the reduced utilization of heat pumps. If the heating demand, covered by heat pumps, is drastically reduced (as is the case when combining energy saving and production strategies) the fuel savings due to the high efficiency of heat pumps are reduced with an amplification factor that equals the heat pump's COP.

Overall fuel savings in the district heating sector amount to 8.2 PJ and to 13.2 PJ in the individual heating sector when combining savings with production strategies. Adding heat pumps in the individual heating sector further reduces the total fuel consumption by 1 PJ. The total national savings potential, which could be realized by implementing savings and production strategies in the entire sector of investigated buildings, could yield fuel savings on the order of 20.1 PJ.

4.2.3 CO₂ emissions

CO₂ emissions saving potentials are obviously strongly correlated to the fuel savings in the respective sectors. This becomes clear when comparing Figure 12 with Figure 11. The smallest level of reduction is observed in the district heating sector of the production scenario at a relative decrease of 0.7% of the national CO₂ emissions. In accordance with the fuel savings, the largest emission saving potential can be realized when applying the savings strategy to the individual sector in combination with the use of heat pumps. The total national scope for emission savings, if saving and production strategies were implemented with the use of heat pumps, amounts to 3.2%.

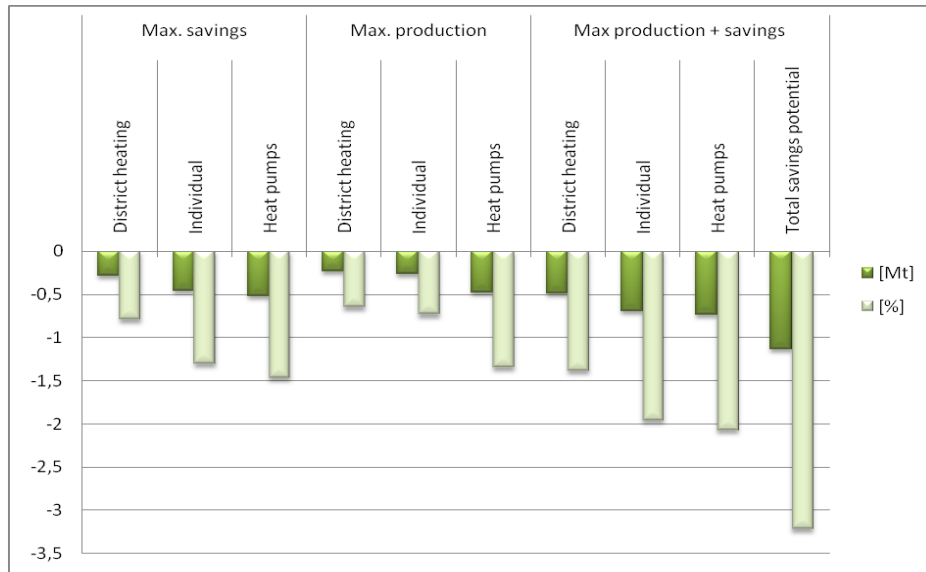


Figure 12: Change in CO₂ emissions from energy conversion with respect to the reference on a national scale

5 Conclusions and recommendations

The implementation of energy savings and production strategies in areas with and without access to district heating was assessed for single family homes build in the period 1961 to 1972. Furthermore, prospective benefits of using heat pumps for space heating in the individual heating sector were investigated. Impacts of these schemes on a possible future Danish national energy system in 2030 were evaluated in terms of fuel usage for electricity and heat production, as well as CO₂ emission savings.

It can generally be concluded that applying the investigated energy strategies to the individual heating sector yields greater benefits than in the district heating sector. The additional use of heat pumps increases the fuel and emission saving potential significantly in both the saving and production scheme. The added benefit of heat pumps even compensates for the generally smaller fuel saving potential of the energy production strategy. This means that applying heat pumps in the individual sector, as part of the energy production strategy, holds greater potential in terms of fuel and emission savings than applying the energy savings strategy to either the district heating sector, or the individual sector without the use of heat pumps.

Combining both savings and production scenarios obviously leads to greater saving potentials. For the district heating and the individual sector without the use of heat pumps, the benefits of both strategies add up directly. When applying heat pumps, however, the additional benefit is smaller relative to that of the separate strategies.

6 References

1. Building integrated energy supply. Aalborg : University of Aalborg, 2011.
2. Prof. P. Capros, Dr. L. Mantzos, N. Tasios, A. De Vita, N. Kouvaritakis. EU energy trends to 2030 - Update 2009. Luxembourg : Publications Office of the European Union, 2010. ISBN 978-92-79-16191-9.
3. J. Kragh and K. B. Wittchen "Danske bygningers energibehov i 2050" (Energy demand of Danish buildings in 2050). Statens Byggeforskningsinstitut, 2010

7 Appendix

Data tables used for up-scaling energy demands from a single house level to national demand.

Data is from Kragh and Wittchen 2010 [3]. Fields in yellow indicate the figures for the investigated building type.

Table 7: Total residential and industrial area (excluding protected buildings and buildings without heat installation) divided into typical building periods.

Period	Farmhouses	Detached houses	Semi-detached houses	Apartment houses	Office/Trade	Total
Before 1850	1,712,494	2,962,354	399,440	592,534	1,494,437	7,161,260
1850-1930	14,255,829	33,713,626	3,230,235	23,104,503	9,431,708	83,735,901
1931-1950	2,155,784	15,883,163	1,863,739	14,126,560	3,215,073	37,244,319
1951-1960	735,419	12,657,356	2,160,128	7,608,238	2,991,769	26,152,910
1961-1972	789,239	38,350,459	4,604,885	13,795,084	10,813,507	68,353,174
1973-1978	633,463	22,035,066	3,747,351	4,359,616	5,825,582	36,601,078
1979-1998	971,011	17,692,632	12,916,228	7,745,102	14,452,963	53,777,936
1999-2006	460,053	7,343,160	4,094,308	3,639,600	6,731,902	22,269,023
2007-2010	323,721	4,077,744	1,842,041	2,040,276	4,040,383	12,324,165
Total	22,037,013	154,715,560	34,858,355	77,011,513	58,997,324	347,619,766

Table 8: Calculated unit consumption [kWh/m² pr. year] for heating before implementing energy saving measures. Unit consumption does not cover protected buildings and buildings without heat installation.

Period	Farmhouses	Detached houses	Semi-detached houses	Apartment houses	Office/Trade	Total
Before 1850	124	126	122	114	74	561
1850-1930	131	133	143	131	81	618
1931-1950	142	160	163	135	137	738
1951-1960	142	163	156	118	113	692
1961-1972	104	114	106	101	101	526
1973-1978	75	89	78	94	88	424
1979-1998	50	64	54	91	71	329
1999-2006	43	46	39	54	48	231
2007-2010	15	26	22	30	29	122
Total	827	921	882	870	742	4,242

Table 9: Energy consumption per year [MWh/year]

Period	Farmhouses	Detached houses	Semi-detached houses	Apartment houses	Total
Before 1850	212,399	371,802	48,819	67,726	700,747
1850-1930	1,870,352	4,479,837	460,467	3,025,283	9,835,939
1931-1950	307,154	2,546,692	304,552	1,913,995	5,072,393
1951-1960	104,436	2,058,834	337,216	896,776	3,397,262
1961-1972	82,317	4,388,025	487,377	1,396,602	6,354,321
1973-1978	47,680	1,965,508	290,791	411,195	2,715,175
1979-1998	48,142	1,127,005	693,977	707,895	2,577,020
1999-2006	19,993	338,587	159,429	196,754	714,762
2007-2010	4,729	106,792	40,634	60,982	213,138
Total	2,697,203	17,383,083	2,823,262	8,677,208	31,580,756